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PSEUDORANDOM POSITION ENCODER WITH IMPROVED ZERO POSITION ADJUSTMENT*

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Abstract. *Pseudorandom position encoder, which employs two code tracks for absolute position measurement, represents one of the latest trends in the development of the absolute position encoders. One sensor head is used for pseudorandom code reading and two additional sensor heads are used for generating synchronization pulses and motion direction determination. Special attention is devoted to the zero position adjustment after the installation of the encoder on the motor shaft. A novel solution for the improved zero position adjustment incorporated in the functional algorithm of the encoder is presented in this paper. The presented solution offers a reliable procedure for the zero position adjustment, taking into account possible motion direction changes during the zero position adjustment process. The algorithm for the zero position adjustment executes only once and does not participate further in the absolute position measurement process. The functioning of the proposed algorithm is described in more details considering one concrete example of the encoder.*

Key words: *pseudorandom position encoder, zero position adjustment*

1. INTRODUCTION

Pseudorandom position encoders are used for position determination, as well for the detection of the movable system's movement direction and velocity. Their broad application range extends over factory automation systems and manufacturing robots, transportation systems, portable equipment, radar systems, telescopes and medical equipment. Pseudorandom position encoders have a vast number of applications in all industrial branches due to their high accuracy and high reliability.

These encoders are representatives of the group of absolute encoders even though their disc is more similar to an incremental encoder disc. In Fig. 1 an example of the pseudorandom position encoder code disc is presented. One can notice that along an external code track, an inner synchronization track is located. Both tracks consist of transparent and nontransparent segments, so for the proper position determination an appropri-

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ate optical detection method has to be applied. The adoption of the mentioned tracks' layout results in the code scanning reliability increase, needed for the high quality of the encoder functioning. The synchronization track can also be used for generating of additional two bits in the output code word. The inner synchronization track is identical to one track of incremental encoder, while external track, or code track, is encoded using a pseudorandom code in such a manner as to provide the remaining important bits in the formation of a complete absolute output code word. By reading just one new bit of the applied pseudorandom code from the code track, a unique n bits long code word for each new position of the encoder is provided [1]. The pseudorandom code words, arranged longitudinally on the track, are overlapping in such a manner that the first (n-1) bits of the current code word are identical to the last (n-1) bits of the previous code word [2]. Any n bits long code word, provided by scanning of the pseudorandom binary sequence (PRBS) using a window of width n, is unique and may fully identify the absolute position of the window in relation to the start of the PRBS. The code disc with pseudorandom code track consisting of 31 bits, generated with $n = 5$ bit shift register, is presented in Fig. 1.

To obtain the output code word three detectors need to be employed. Serial reading of the code bits from the code track is performed using detector or code reading head $x(n)$. Getting the signal from the synchronization track is achieved by using two detectors as with the conventional incremental encoder, i.e. with AUT and VER sensor heads [3]. The number of code tracks in the case of pseudorandom position encoders does not increase with the increase of resolution n. Besides the possibility to determine the absolute position with only one code track, pseudorandom absolute position encoders have the option to sequentially assemble n bits long code words in the bidirectional shift register using one or two sensor heads. This paper examines the case when only one code reading head is used [4-5].

Difficulties that the encoder designers usually deal with when the implementation of the pseudorandom position encoder has to be performed are: zero position determination after encoder installation, code reading, code scanning [6], detection of code reading errors and the conversion of pseudorandom code into native code [7]. In this paper we particularly deal with the problem of how to achieve a proper and reliable direct zero position adjustment after the pseudorandom position encoder installation on the rotating shaft. The solution we are proposing relates to the situation when there is a change in the movement direction during zero position adjustment.

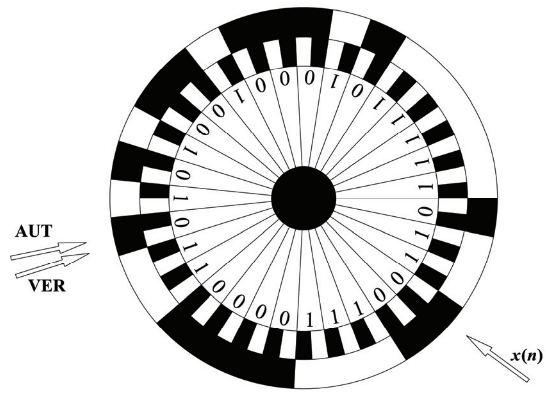

Fig. 1. An example of the pseudorandom position encoder code disc

2. SERIAL PSEUDORANDOM CODE READING WITH ONE SENSOR HEAD

Technical problems with spatial distribution of n sensor heads for pseudorandom code reading are common, especially when encoders of high resolutions are used. With linear pseudorandom encoders of high resolutions it is usually mandatory to distribute n sensor heads for code reading in longitudinal direction at very small distances of order of couple of µm. The fact that the distance between sensor heads changes with encoder resolution represents even more severe problem for the encoder production technology. In any case it would be better if the code reading method requires a lower number of code reading heads. There is a possibility to use only one code reading head, as proposed in [8]. This code reading method, usually called serial or sequential, is described below. The length of the PRBS used for position determination is 2^n-1 bits, i.e. the PRBS consists of 2^n-1 randomly distributed zeros and ones $\{S(p)/p=0,1,\ldots,2^n-2\}$.

Fig. 2 gives the graphical representation of the movable system (MS), whose absolute position can be obtained with the serial code reading method with one sensor head. The explanation of the bidirectional shift register functioning and its content forming for either movement direction is given below.

When the MS is moving to the left (CCW in the case of rotary pseudorandom position encoder), the control signal RGT="0" (logical value of zero at the RGT output of the control logic) shifts the content of a bidirectional shift register, used for the formation of a code word, to the right. Let the MS move from the position p+1 to a new position p. This kind of movement resultes in generation of a "LOAD" pulse which, when only one code reading head $x(n)=S(p)$ is in use, puts a new bit in the position $X(n)$ of the bidirectional shift register. At the same time, the previous content of the register is shifted for one position to the right. The newly obtained content of the bidirectional shift register is now:

$$\{X(k) = S(p-k+n) / k = n,...,1\} . \qquad (1)$$

The previous expression represents n bits long code word corresponding to the new position of MS.

When moving to the right (CW in the case of rotary pseudorandom position encoder), the control signal RGT="1" shifts the bidirectional shift register content to the left. Let the MS move from the position p-1 to a new position p. Due to "LOAD" pulse generation, the unique code reading head puts a new bit in $X(1)$ position of the bidirectional shift register. At the same time, the previous content of the register is shifted for one position to the left. The newly obtained content of the register is:

$$\{X(k) = S(p-k+1) / k = n,...,1\} , \qquad (2)$$

representing exactly n bits long code word which corresponds to the position p-n+1. Because of this systematic error, after pseudorandom/natural code conversion, it is necessary to make a correction of +(n-1). At the same time, due to specific distribution of the AUT and VER synchronization heads and $x(n)$ code reading head, it is necessary, when moving to the right, to make a correction of +1. The correction can be performed activating the appropriate inputs of a parallel adder whenever the MS is moving to the right. In other words, when MS is moving to the right, the obtained position value converted to the natural code need to be increased by n.

This solution implies the problem that, after the movement direction change, MS has to move *n* consecutive quantization steps in the same direction to reestablish its absolute position [8].

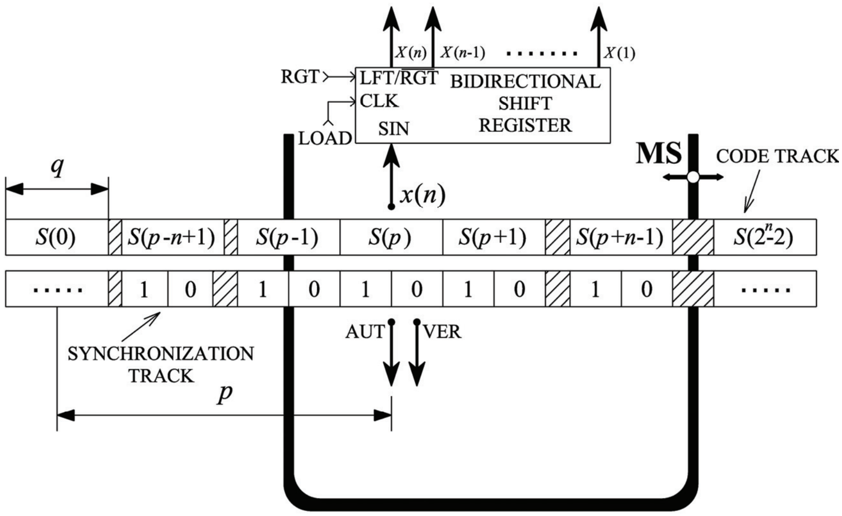

Fig. 2. Serial code reading method with one code reading head

To solve this problem of losing position information after each movement direction change, in practice are applied different methods which usually include additional operations after each movement direction change. These operations can be performed with an additional counter and some logic circuits for the realization of the protection mechanism, so that the content of the shift register always corresponds to the current position [9-10].

3. Algorithm for Improved Zero Position Adjustment

For providing the information about the motor shaft position in motion control systems, the pseudorandom position encoder is mostly used. After mounting the encoder on the movable system shaft, some unmatchings in the starting position of the encoder and the shaft can happen. Therefore, what is needed is to adjust the zero position of the position encoder to the corresponding zero position of the movable system [11, 12]. Fortunately, the pseudorandom position encoders, thanks to some features of the pseudorandom binary sequence, can provide a sophisticated solution of this problem. The pseudorandom/natural code conversion, as important functional part of pseudorandom position encoder, directly affects the absolute position measurement time and performes in relation to the pseudorandom code word which refers to the zero position. This code word is not any special code word, i.e. it is the pseudorandom code word read from the PRBS code track. The main idea of this paper is based on the previous facts, particularly on the fact that any pseudorandom code word can be accepted as the initial code word. In order to adjust the zero position directly, in the paper there is suggested a solution which reliably determines the code word which will be accepted as the initial code word. Afterwards, this code word will be stored in the encoder's flash memory and used as the initial code word in relation to which the code conversion process is performed.

The proposed adjustment procedure of the encoder's zero position will be explained through an algorithm which is shown in Fig. 3. Our solution is based on the fact that direct zero position adjustment is performed only once, after encoder installation. By observing this algorithm, one can see that the parameter Z gives the information whether the zero position is already determined or if it needs to be determined. The Z=1 means that the zero position is already determined. This parameter is put in the encoder's flash memory and permanently stored, which means that even after encoder's restarting it will remain memorized in flash memory avoiding any further algorithm execution. In this way measurement time does not increase. If direct zero position adjustment is not performed, Z=0, the encoder goes through the steps of the algorithm shown in Fig. 3.

As the proposed solution implies the use of just one code reading head the system has to move n steps to record new n bits in the same direction as complete code word can be formed. In the first part of the algorithm the goal is to form n bits long code word (in the same direction), and simultaneously memorize the information about the position of the formed code word in relation to the zero position (for that purpose the parameter j is used). Those n bits are loaded in the bidirectional shift register. After that, depending on the current movement direction and the value of parameter j, the content of the shift register is shifted-back or shifted-forward according to direct or reverse generation law until it is matched with the content (code word) corresponding to the zero position. This content of the shift register is temporary stored in the flash memory. The presented solution offers the possibility for the zero position adjustment in the case when there is a movement direction change during the zero position adjustment, which is not often the case in practice. The example which illustrates five different cases of n-bit code word formation is shown in Fig. 4. The 5-bit code word which represents the zero position is shaded. The formed code words have different positions in relation to the zero position and they are formed for different movement directions. So, in case 1 of the example presented in Fig. 4, the formed code word must be shifted-back according to the reverse generation law for j=6 steps.

After the enrollment of the complete code word in the shift register and storing in the flash memory, the next step is the examination of its correctness, which will provide us a high reliability of the information about the zero position. This particular algorithm procedure executes through the loop. The loop begins with the examination of the read bits that follow after the stored code word, i.e. the following bits are going to be compared with the generated PRBS bits, so their correctness can be checked. The examination is done on bit per bit bases, and if any of the bits does not match with the corresponding and expected value from the PRBS sequence, the loop breaks. Shift register shifts-back or shifts-forward for j steps from the zero position according to direct or reverse generation law and generates a bit which should be read with the sensor head. The examination is performed until minimum $2n$ bits are checked in one or in the other movement direction. This step is introduced with a goal of obtaining reliable information about the zero position even in the presence of the shaft vibrations or oscillations when only few bits left and right from the current position are examined.

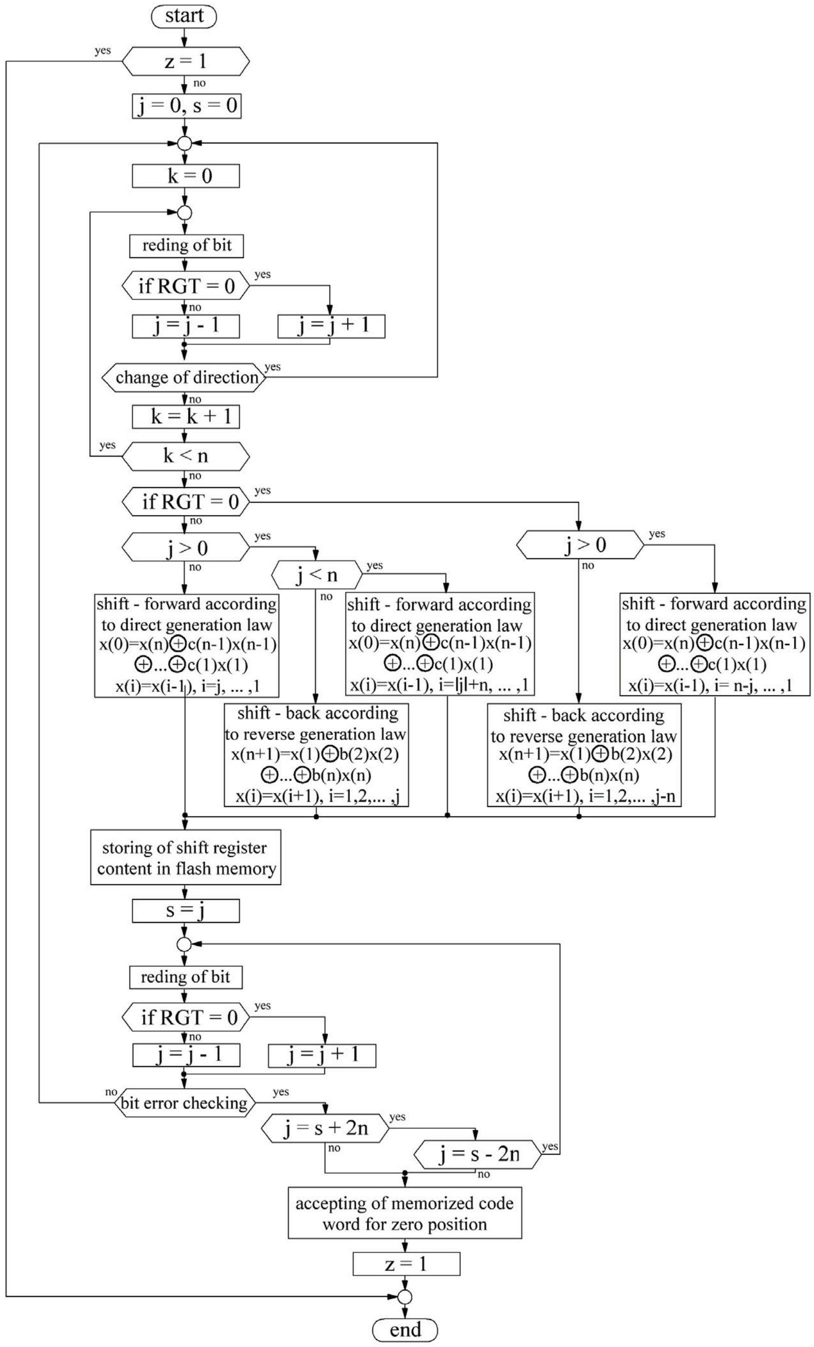

Fig. 3. The proposed algorithm for reliable zero position adjustment

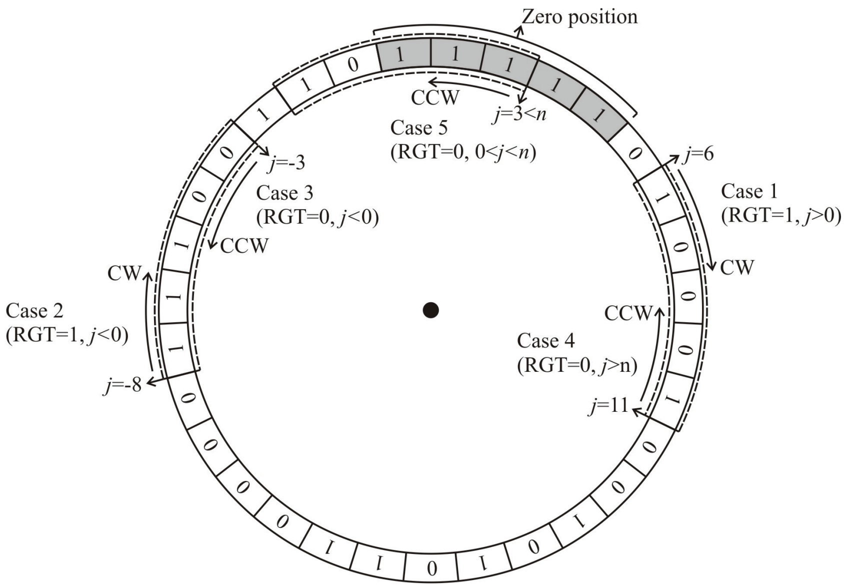

Fig. 4. Different scenarios in zero position adjustment process

If all examined bits match with the expected corresponding values the code word entered in the shift register becomes the correct and reliable information about the encoder zero position. The determined and previously stored n-bit code word is then accepted as valid and permanently stored in the encoder's flash memory along with the parameter Z=1.

It is accepted that the minimal number of bit positions that should be examined in one movement direction to prove the code word correctness equals $2n$, and if all the bits match with the corresponding bits generated using shift register and direct or reverse generation law we can be sure that there is no error detected. At least $2n$ bits need to be checked in either movement direction, so in each scenario of MS movement n new bits are available for checking. This choice is made due to the fact that in some scenarios the bits which should be read and checked are already loaded in the shift register.

The pseudorandom position encoder with parallel code reading method has a relatively easier zero position adjustment procedure [11, 12]. This encoder employs an integrated circuit which has a linear photodetector array for simultaneous reading of all n bits from the pseudorandom code track. However, in this paper for the zero position adjustment purpose, reading of the photodetector array is performed first, and then the adoption of the read code word as the initial code word is done.

With the proposed procedure, any employment of the correction factor, which would be added or subtracted from the current read value in each subsequent process of the position measurement, is avoided. Also, the position measurement time and the complexity of the encoder design are not increased with this procedure. So, in accordance with the previously given description, the proposed solution for zero position adjustment looks like a good approach and proves great possibilities of the pseudorandom position encoders in relation to many requests which will become standard in time.

4. CONLUSION

In this paper the features of the PRBS sequence for encoder zero position adjustment after the first mounting on the movable system shaft have been exploited. An algorithm, which successfully deals with this aim, has been proposed. This algorithm prevents the possibility for the code reading errors, increasing the reliability of the obtained information. The determined code word, which refers to the zero position, is accepted and memorized in the flash memory of the encoder. The presented algorithm gives the reliable information about the zero position even in the case of the rotating shaft oscillations during the zero position adjustment, when the code words can be formed in either movement direction. A necessity for the permanent memory does not represent an additional system complexity because the modern encoders should or will become the intelligent sensors. The proposed solution for direct zero position adjustment can further improve the rank of the pseudorandom position encoders on the position encoders market.

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